Search for new physics with XENONnT

XENON

INFN TORINO

INAF ISTITUTO NAZIONALE DI ASTROFISICA OSSERVATORIO ASTROFISICO DI TORINO

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On behalf of the XENON Collaboration

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9 / 9 / 2022 – IPA 2022

XENON collaboration

XENON

~170 scientists, 27 institutes

Columbia | KIT | Nikhef | Muenster | Stockholm | Mainz | MPIK, Heidelberg | Freiburg | Zurich

Chicago

Tsinghua

UCSD

Tokyo

Rice

Nagoya

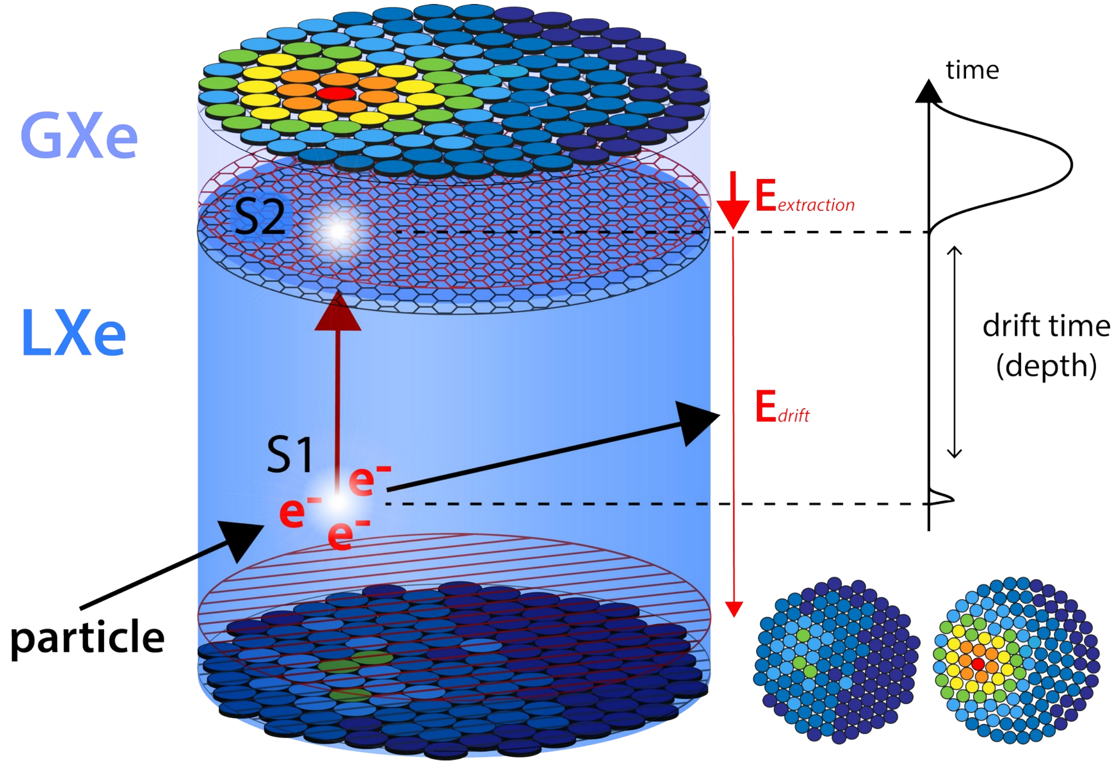
Purdue

Kobe

Subatech | Coimbra | LPNHE | Torino | Bologna | L’Aquila | LNGS | Napoli | Weizmann | NYUAD

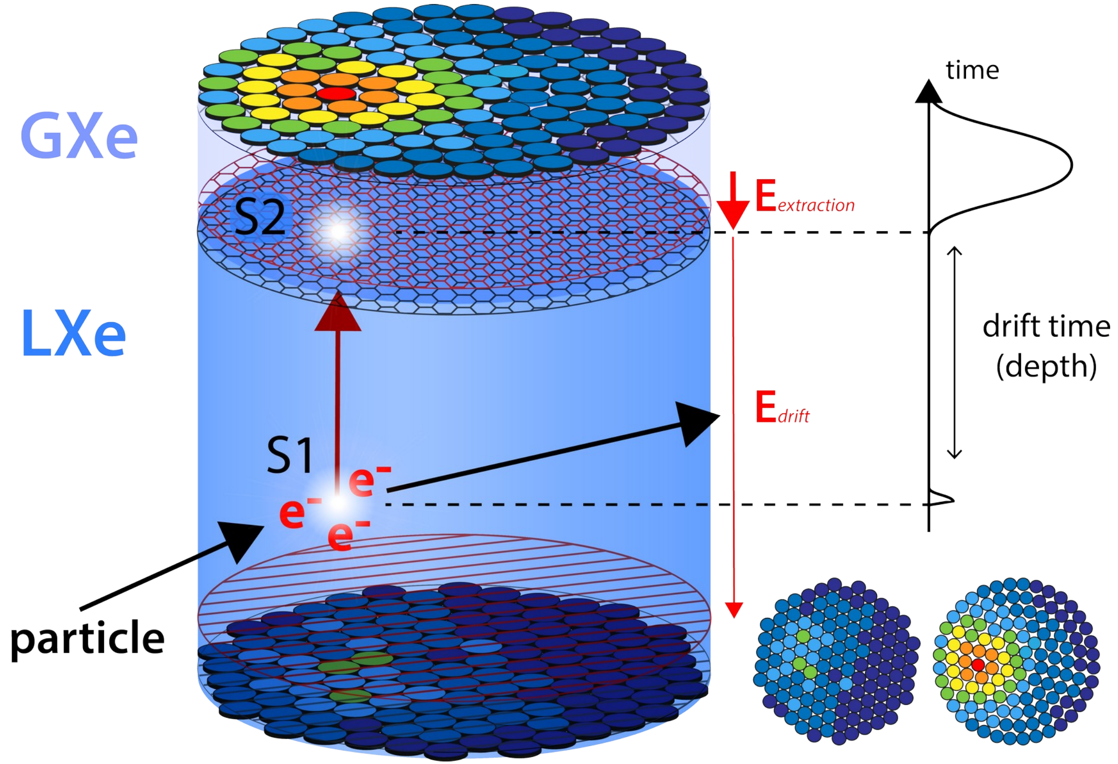
XENON collaboration

Dual-phase XENON TPC



- S1 prompt scintillation
- S2 proportional to ionization
- S2/S1 to discriminate nuclear recoils (NR) and electronic recoils (ER)
- 3D position reconstruction
- Low energy threshold
- Energy reconstruction combining S1 and S2

Dual-phase XENON TPC



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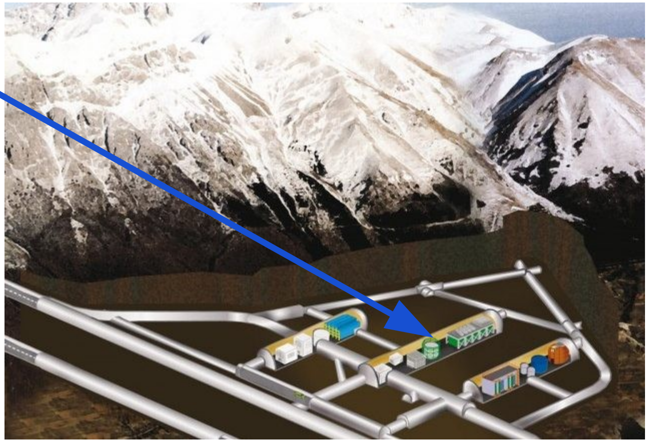
Ideal for dark matter and rare processes search

The XENON Project at Gran Sasso

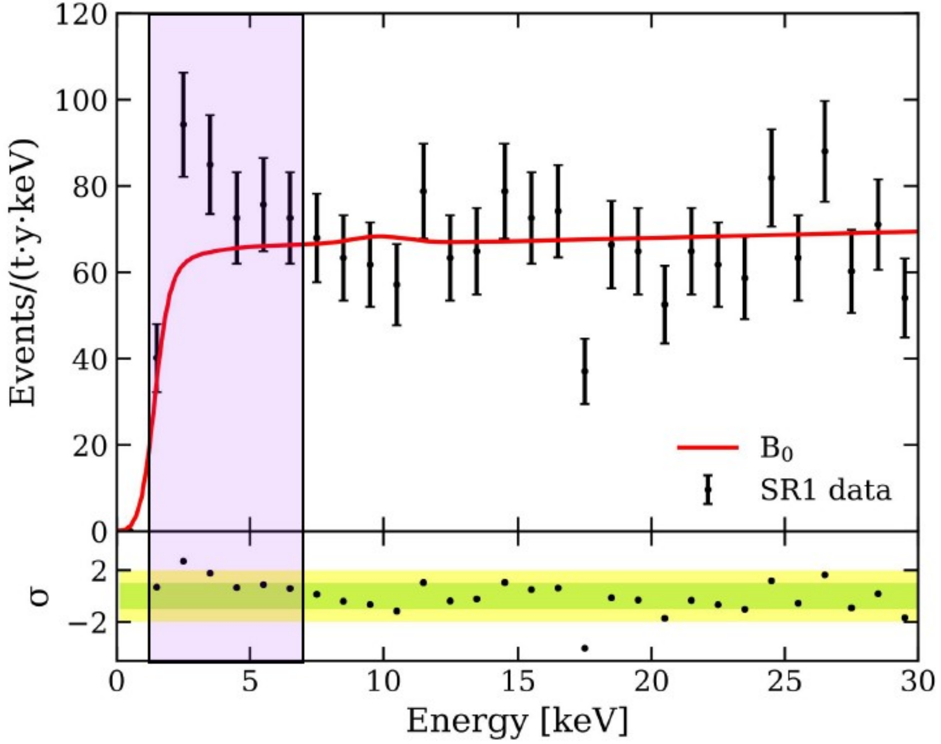
- All detectors of XENON Project operated underground at Laboratori Nazionali del Gran Sasso (Italy)

- 1.4 km rock coverage (3800 m w.e.) provides factor 10^6 reduction of μ flux



Recap: search in ER band with XENON1T

Excess observed in 1-7 keV



E. Aprile et al., Phys. Rev. D 102, 072004 (2020)

- 285 events observed vs (232±15) expected (3.3σ fluctuation)
- ^{37}Ar contamination ruled out:
  - it would require too high air leak
  - best-fit for a mono-energetic peak is at (2.3±0.2) keV (^{37}Ar peak is at 2.82 keV)
- ^{3}H contamination is possible (as tritiated hydrogen HT, not as water)
- New physics can explain the excess: solar axions or neutrino magnetic moment

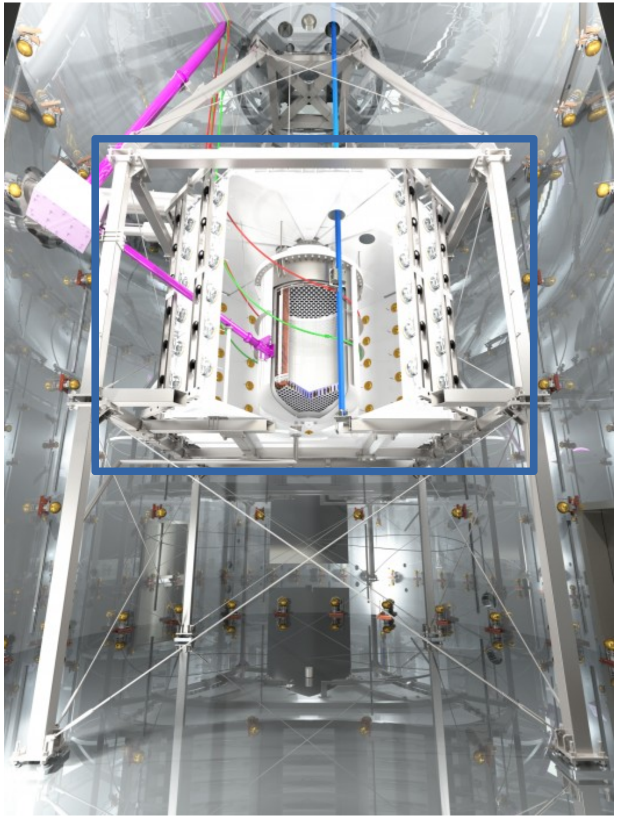
Upgrades for XENONnT

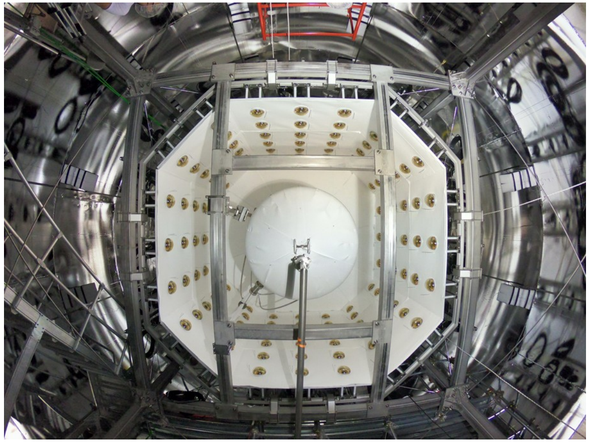
A new TPC

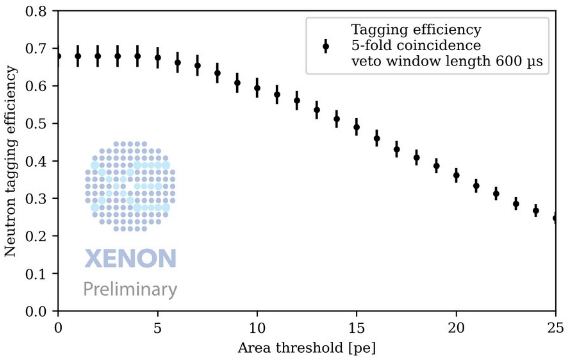
- Drift length 1.5 m (XENON1T had 1 m)
- Active Xe mass 5.9 t (2 t)
- Double the number of PMTs to 494
- Light detection efficiency to 36%
- Carefully selected materials to minimize background
- Field shaping rings with tuneable potential

Upgrades for XENONnT

A Neutron Veto





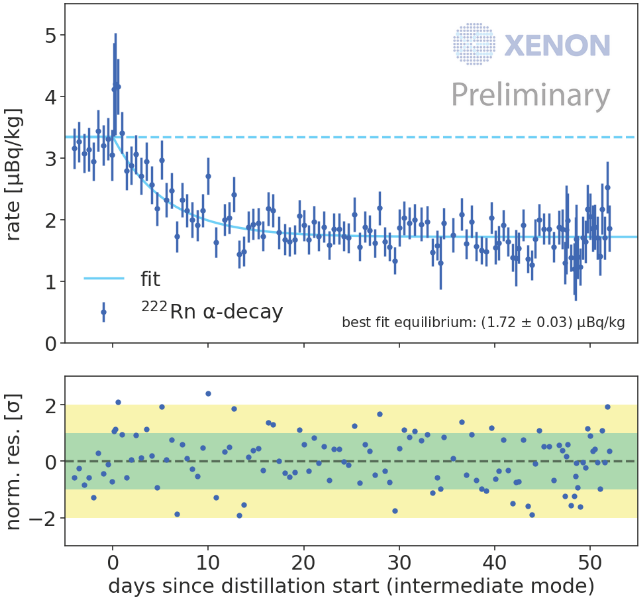


- Water cherenkov detector built around cryostat with 120 PMTs inside an enclosure of reflective panels
- Goal is to tag neutrons which contribute to background in WIMP search
- Now running with pure water, tagging efficiency 68%
- It will be doped with Gd to increase performances

Upgrades for XENONnT

A Radon removal column

arXiv:2205.11492



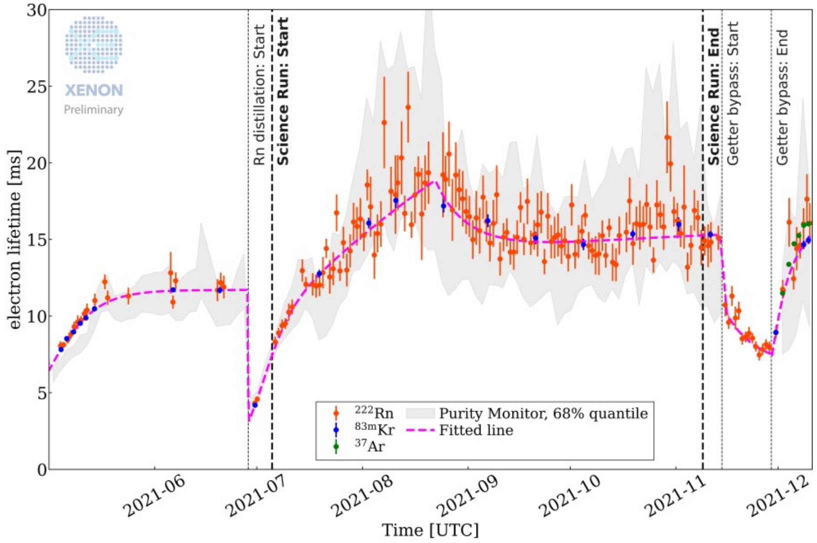
- ^{222}Rn decay chain is most prominent source of background at low energies
- Newly developed Rn removal column handles large Xe flows using Rn-free compressors and heat exchangers

Rn contamination in first science run is 1.7 µBq/kg

It will be reduced to <1 µBq/kg

Upgrades for XENONnT

A new liquid Xe purification system



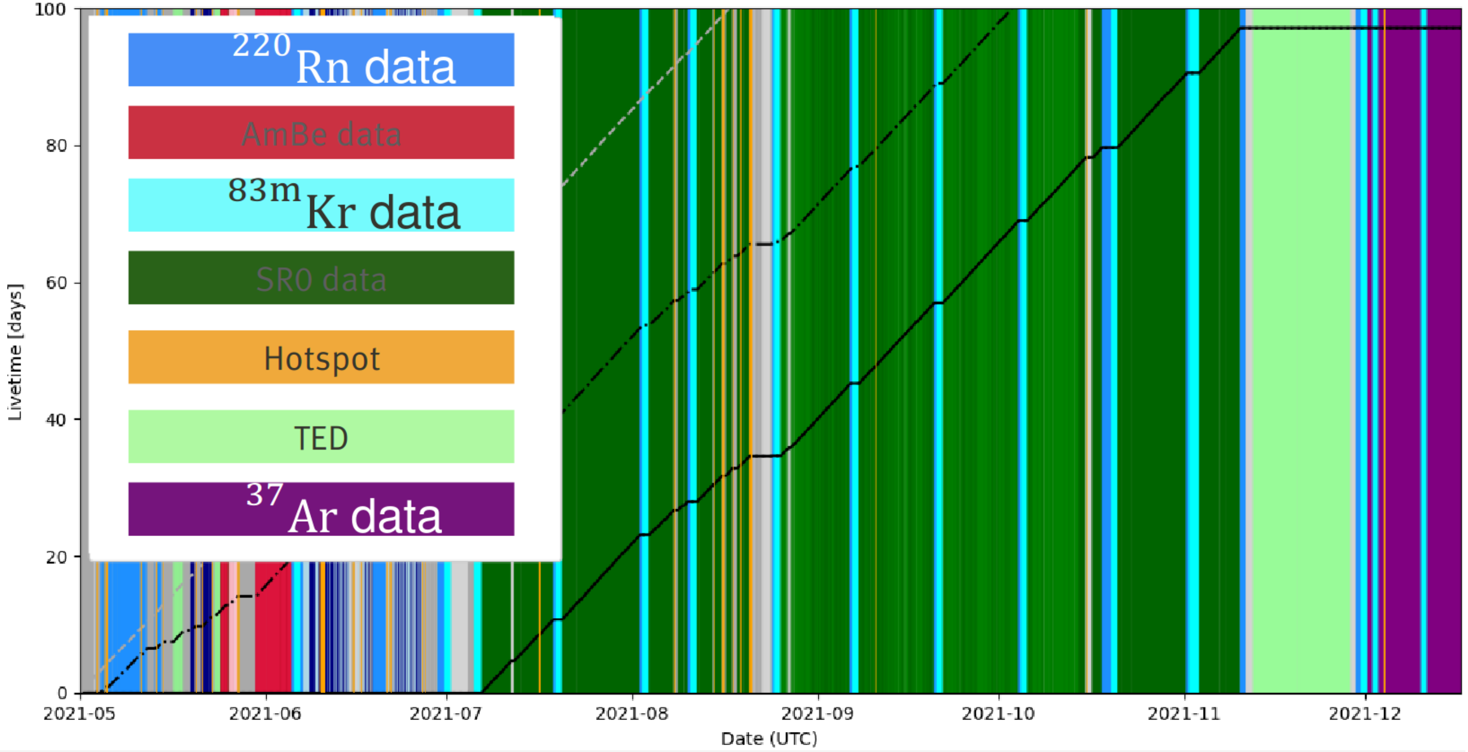
- Replaceable filter units and low Rn emanation, high flow of 2 liters LXe/min

- Electron lifetime > 10 ms in science run (maximum drift time is 2.2 ms)

arXiv:2205.07336

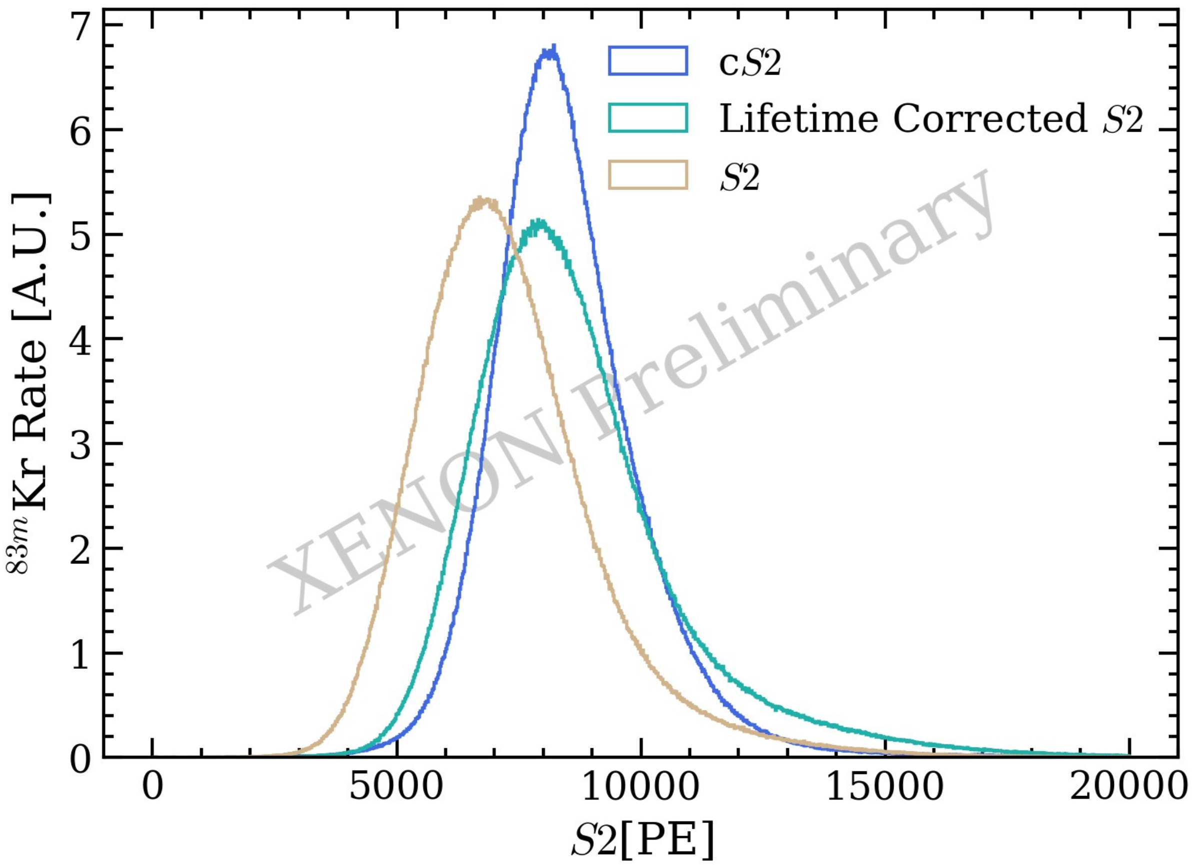
First Science Run - SR0

97.1 days livetime from July 6, 2021 to November 10, 2021



- All but 17 PMTs working, gain stable at 3%
- 23 V/cm drift field
- 2.9 kV/cm extraction field
- Occasional temporary ramp-downs of the anode, due to localized, high-rate, bursts of electrons

Corrections



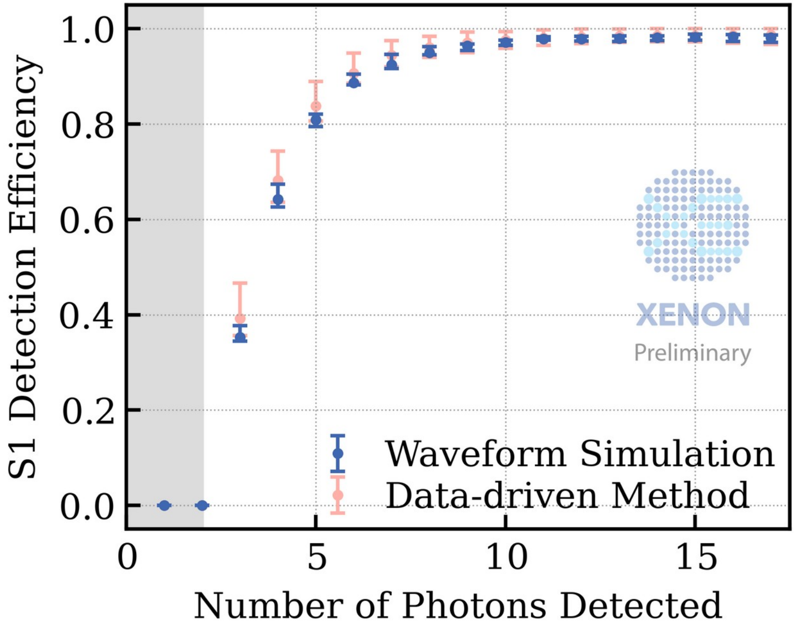
- S1 and S2 signals get corrected to take into account position - dependent response of the detector
- ^{83m}Kr calibration every 2 weeks
- The corrected signals *cS1* and *cS2* are then used in the analysis

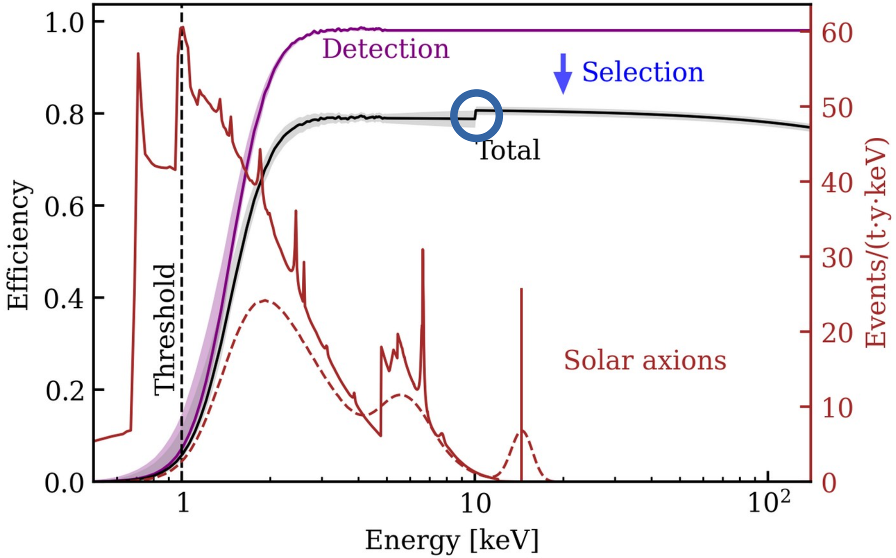
Efficiencies

Detection efficiency validated using simulation and data-driven methods

Good agreement between the two approaches

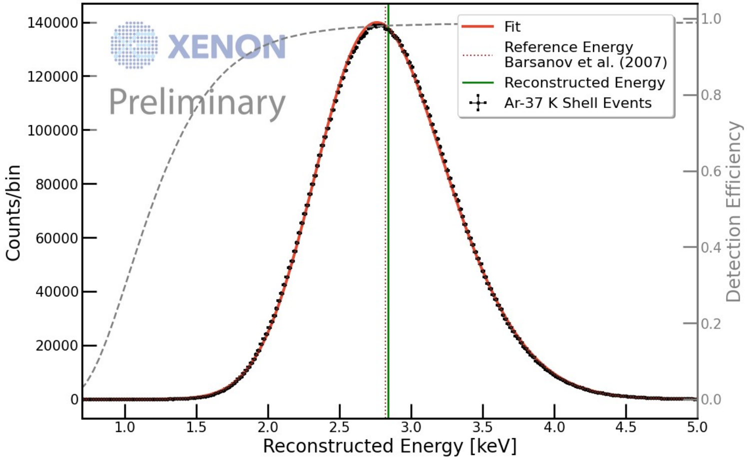
Total efficiency takes also event-selection efficiency into account

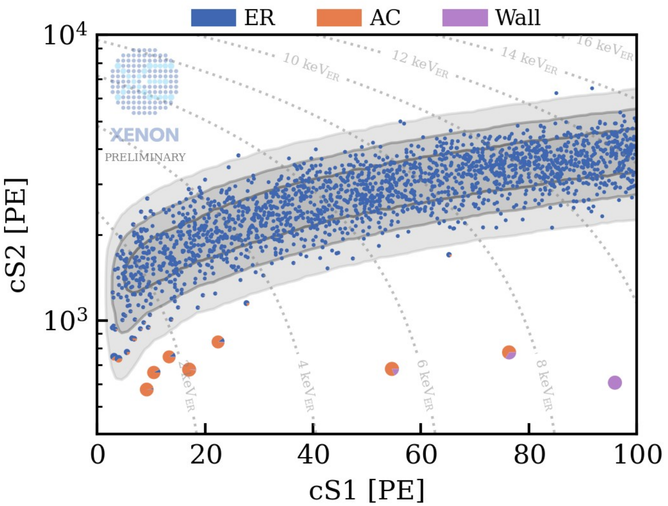


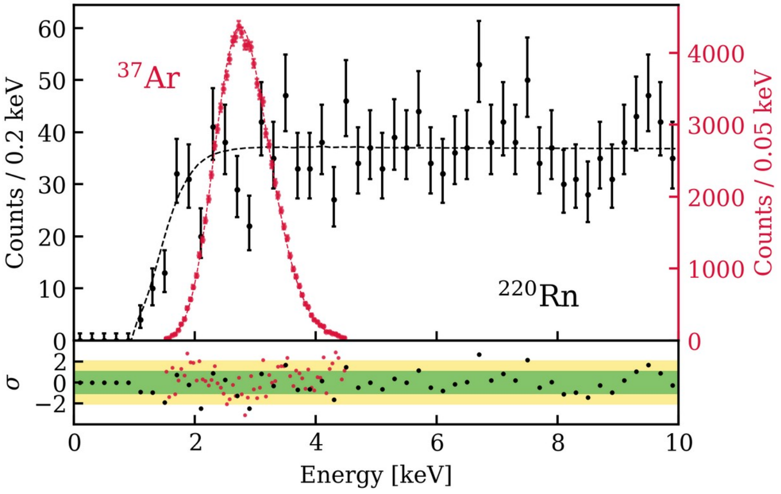


Discontinuity due to still-blinded WIMP search region

Calibrations

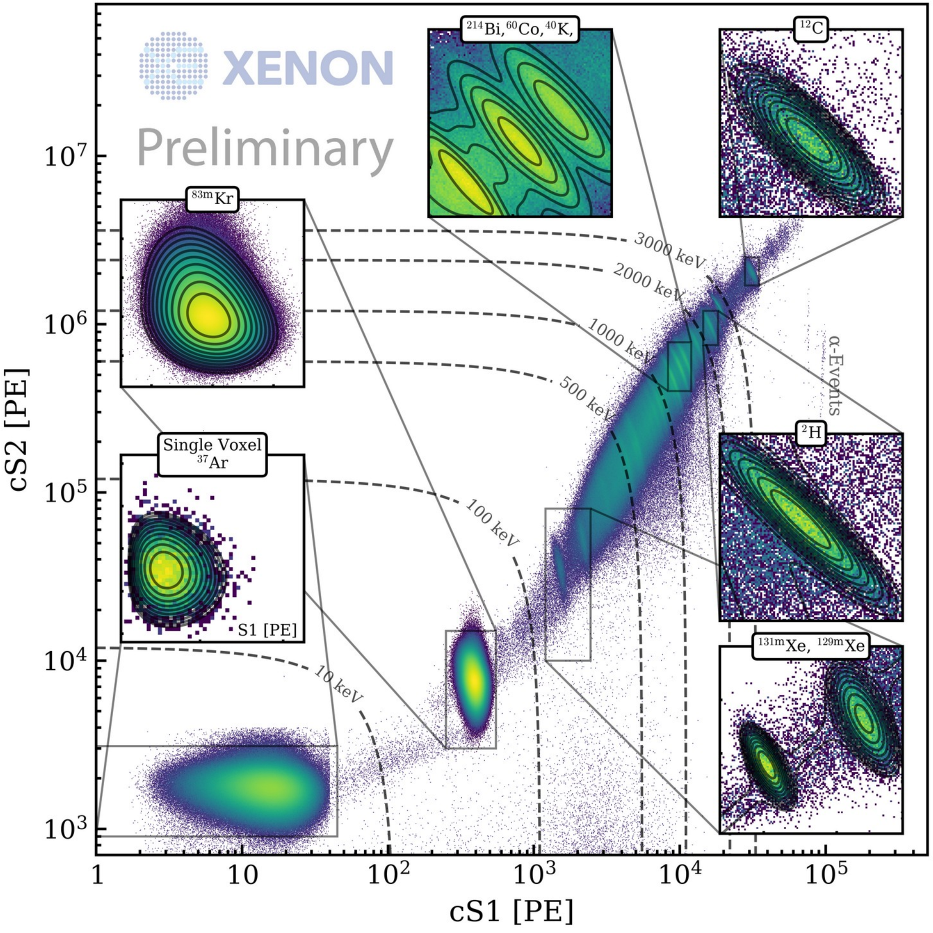


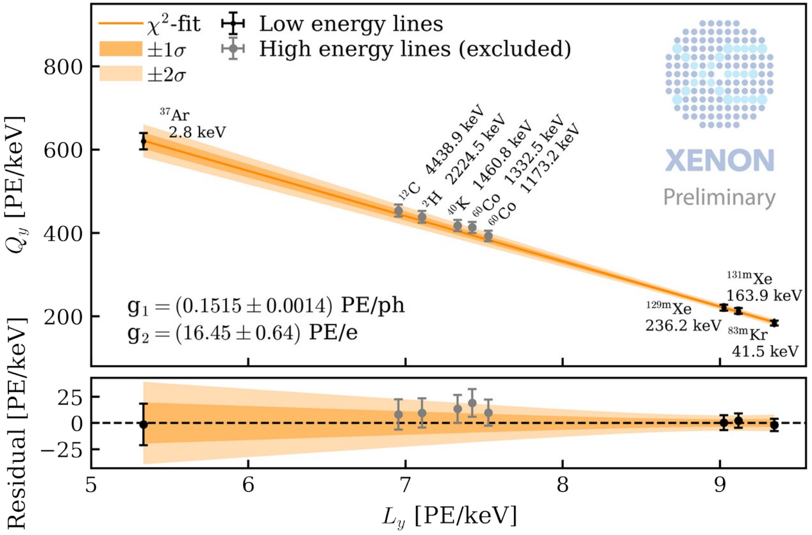




- Two ER calibration sources at low energies
- ^{37}Ar, mono-energetic peak at 2.82 keV
It validates resolution model and anchors energy reconstruction of peaks
- ^{220}Rn, whose daughter ^{212}Pb provides a flat β-spectrum to estimate cut acceptances and validates our energy threshold

Energy reconstruction



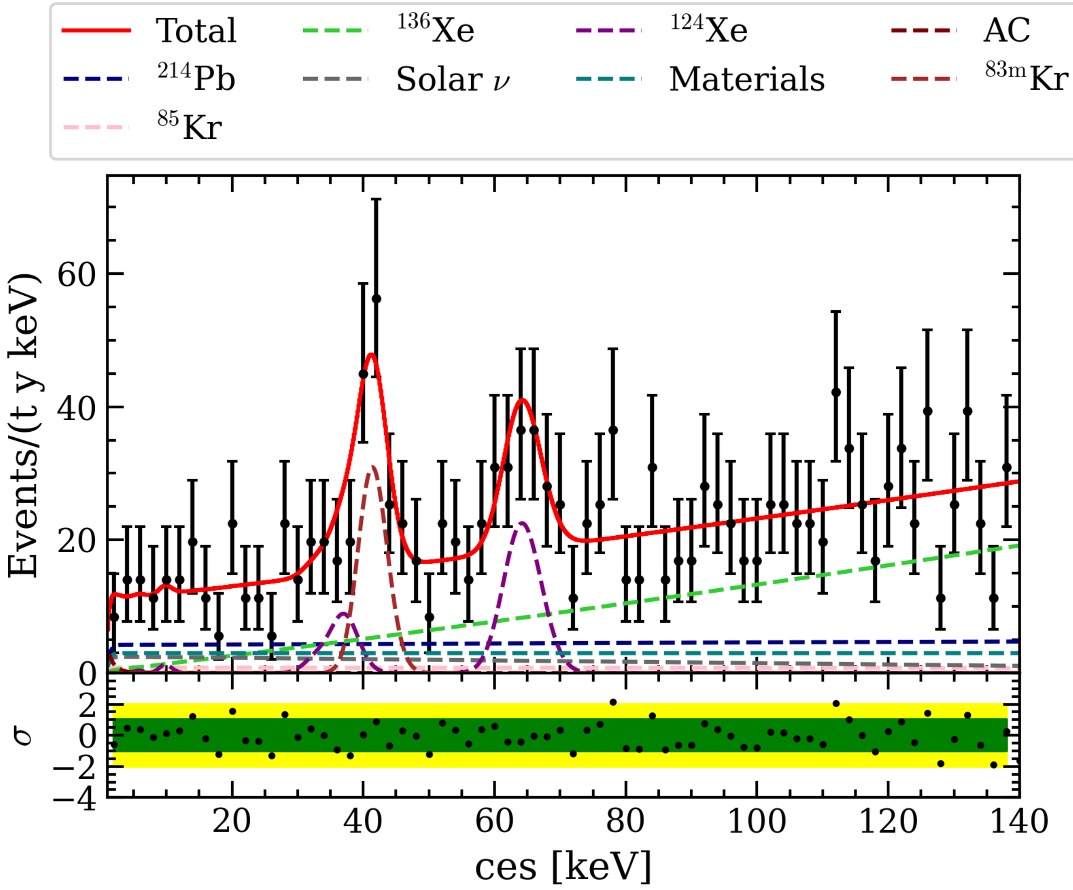


Based on ^{37}Ar, ^{83m}Kr, ^{131m}Xe, ^{129m}Xe

Energy reconstruction (combined energy scale)

$$E = 13.7 \text{ eV} \left(\frac{cS1}{g_1} + \frac{cS2}{g_2} \right)$$

Tritium Enhanced Dataset (TED)



(ces → combined energy scale)

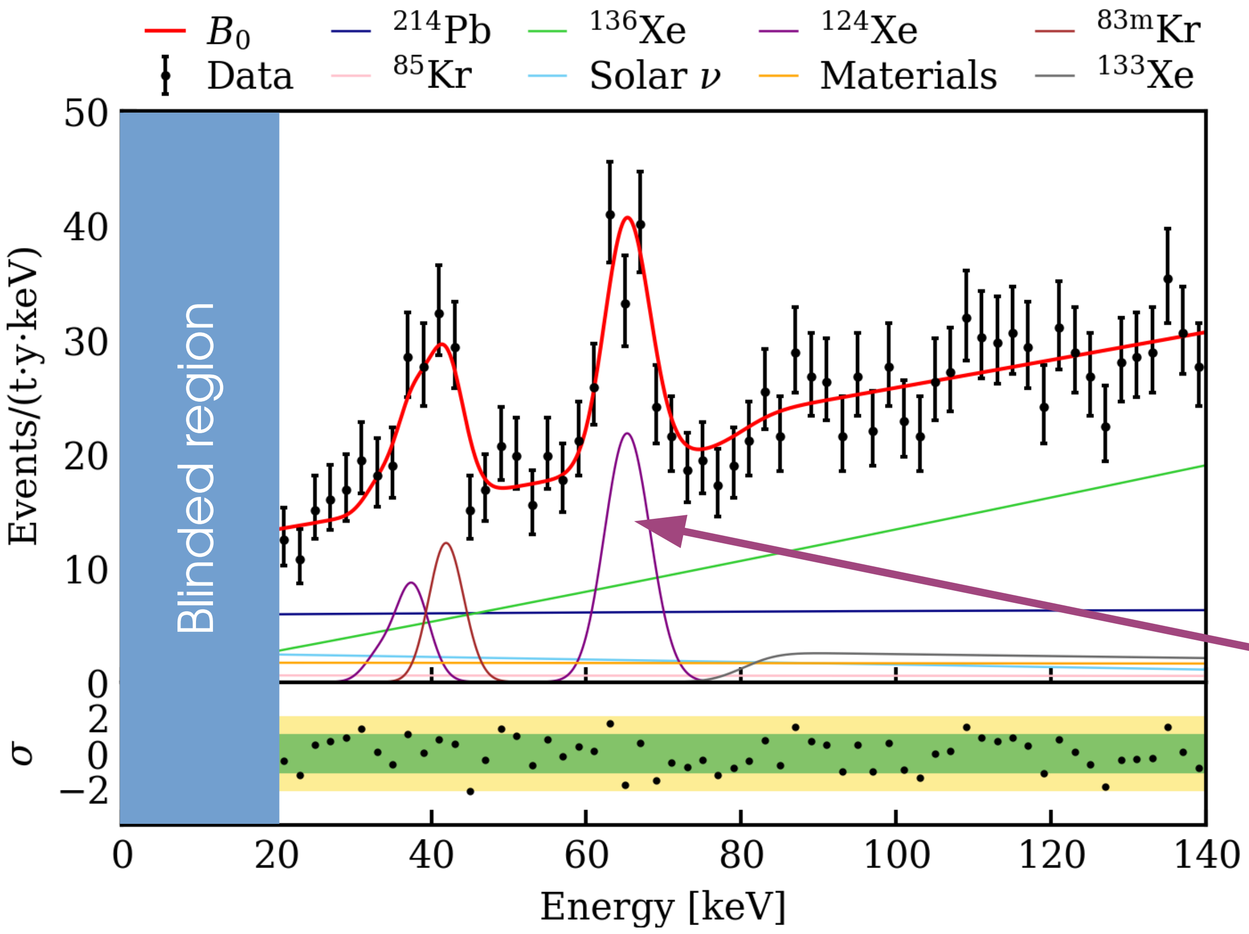
- Measures against ^3H
  - 3 months of outgassing
  - All xenon processed through Kr-removal system
  - 3 weeks of GXe circulation

- After SR0, XENONnT was operated in a mode that bypasses the purification of the gaseous Xe volume for 14.3 days (TED)

- This would enhance the HT concentration in LXe by a factor 10-100

- No evidence was found for a tritium-like excess

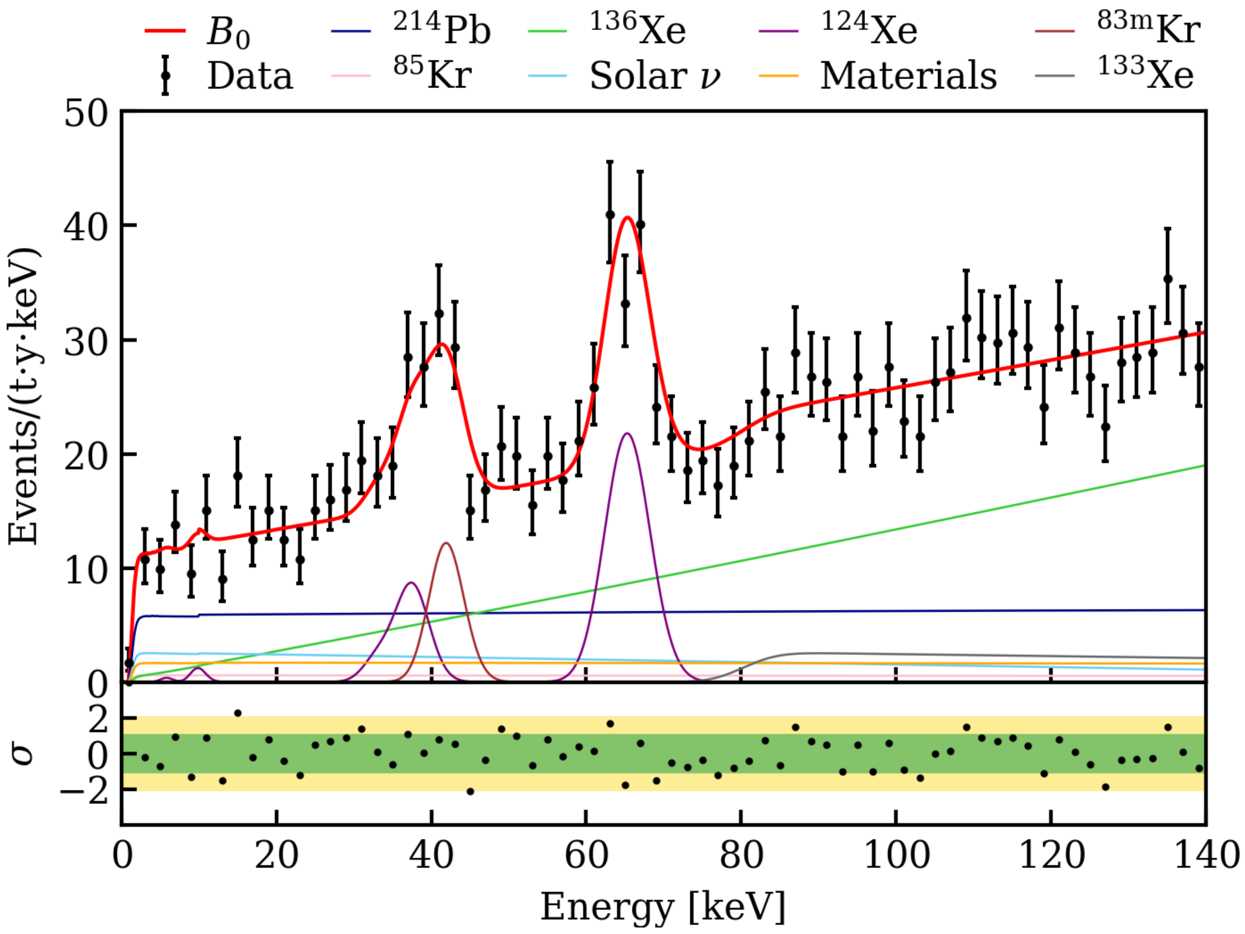
Background model



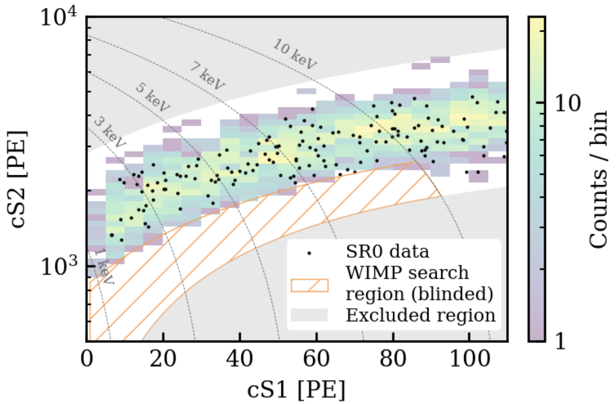
- Background model includes 9 components
- Full blind analysis with various stages of unblinding
- Energy range (1-140) keV
- Fiducial mass (4.37±0.14) t
- Exposure is 1.16 t*y

^{124}Xe 2vECEC was first observed in XENON1T, now it's a useful validation of the energy reconstruction!

Unblinding

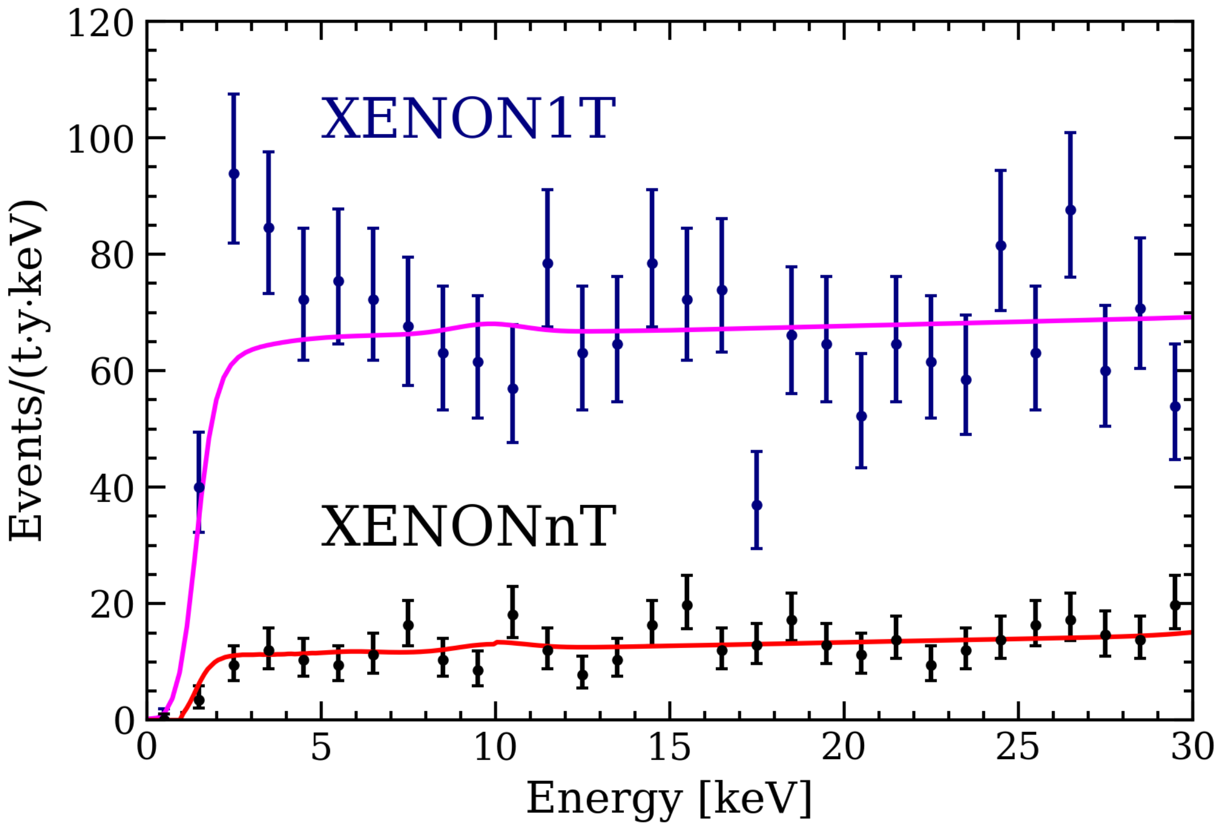


- No excess observed
- Spectral shape is dominated by two 2nd order weak processes
- ^{214}Pb (from ^{222}Rn chain) is still the dominant component below 30 keV



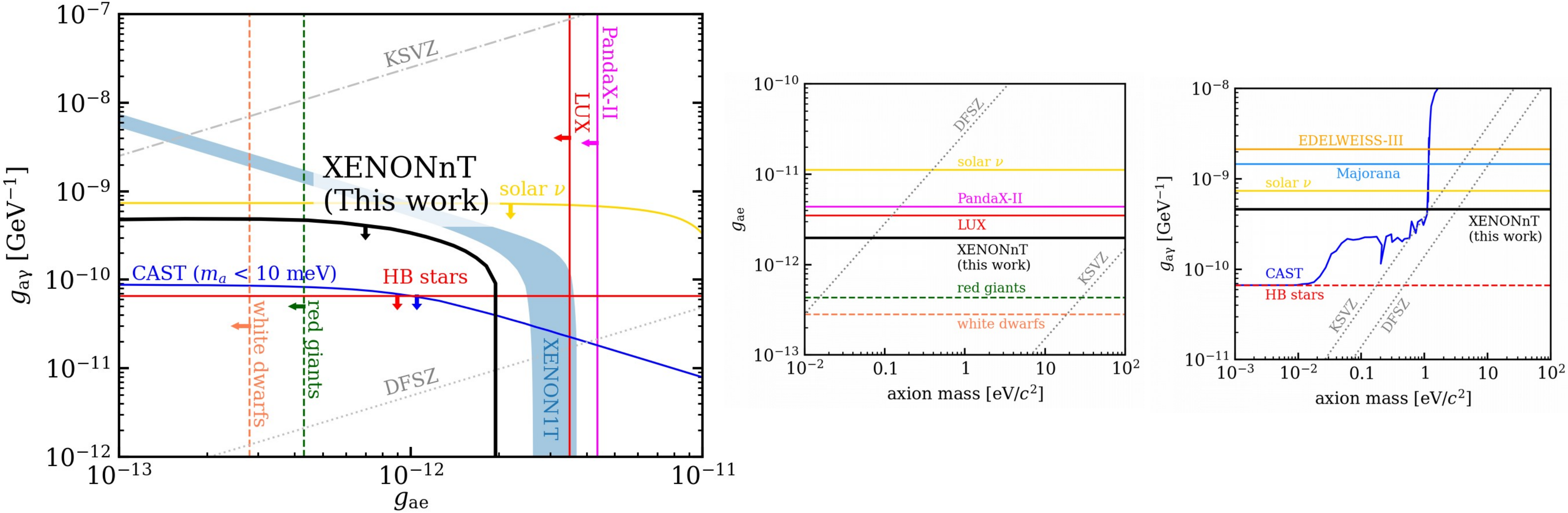
arXiv:2207.11330

Comparison with XENON1T



- (16.1 ±1.3$_{stat}$) events/(t*y*keV) in (1,30) keV
- Factor ~5 reduction wrt XENON1T
- An excess of the XENON1T magnitude is excluded at 8.6σ
- Excess in XENON1T probably due to ^{3}H contamination

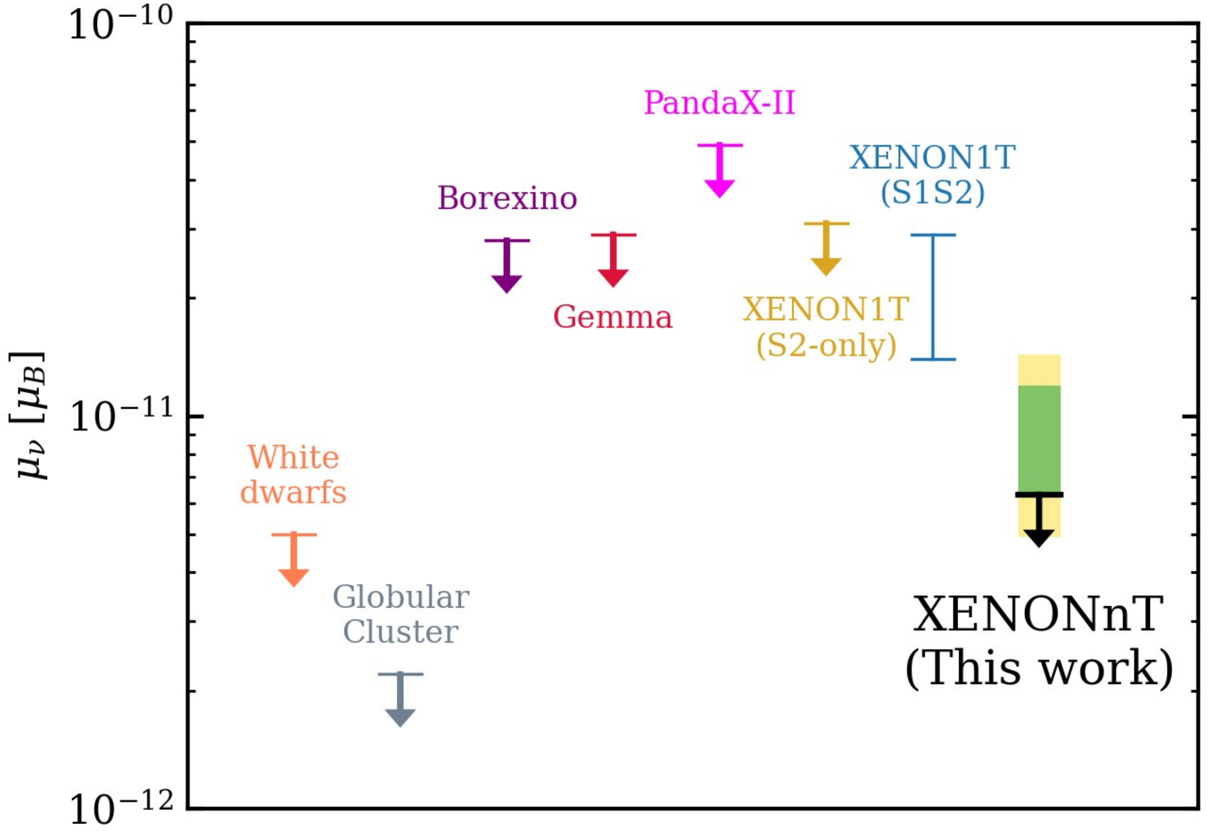
Limits on solar axions



We set new limits on solar axions couplings g_{ae} and $g_{a\gamma}$

Limit on 14.4 keV peak for ^{57}Fe solar axions is < 20 events/(t*y)

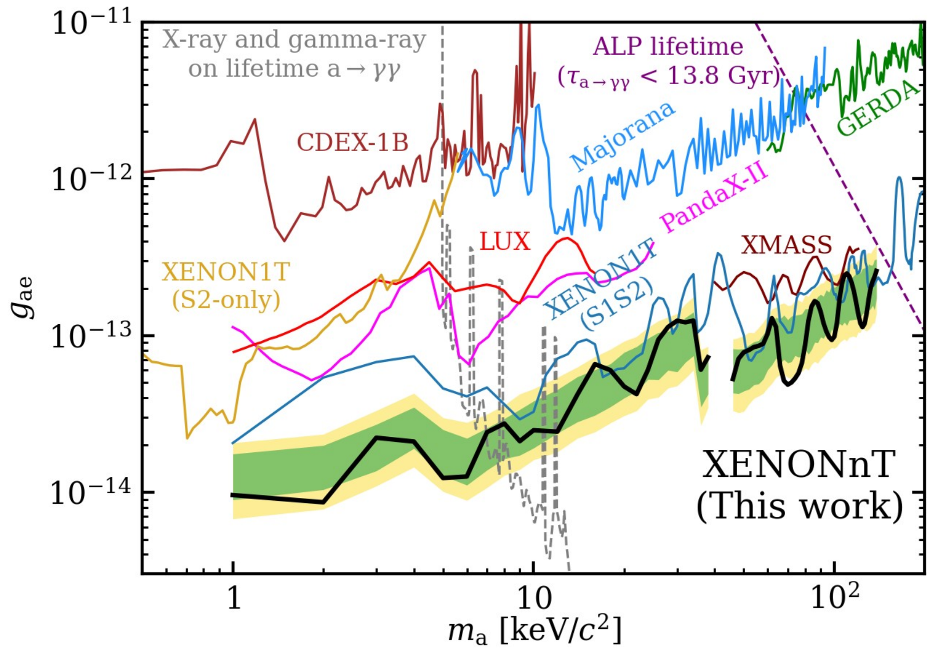
Limit on neutrino magnetic moment



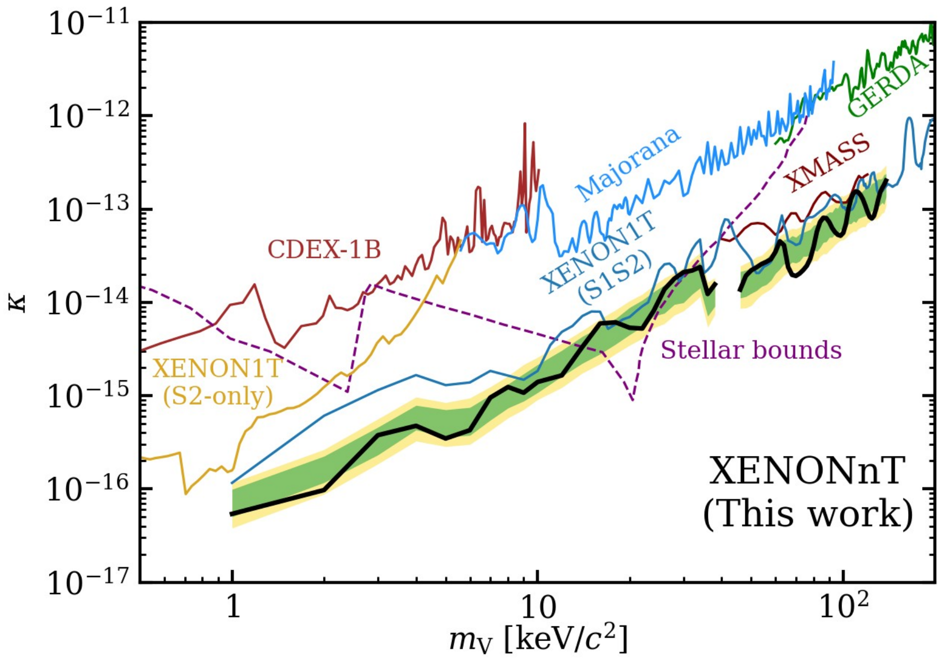
- Constraint on neutrino magnetic moment $\mu_\nu < 6.3 * 10^{-12}\ \mu_B$
- The most stringent limit in any direct detection experiment

Limits on bosonic DM

Axion-like particles (ALPs)



Dark photon

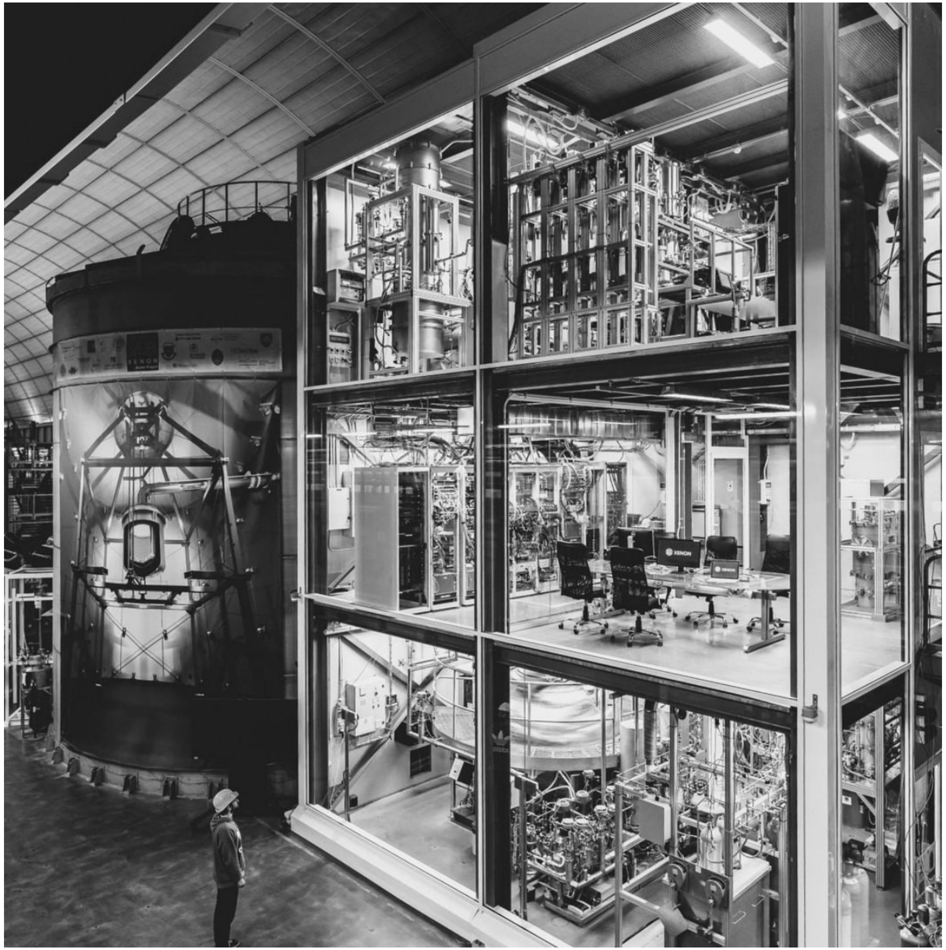


Search for a peak gives null result, new limits are set

Since ^{83m}Kr component (41.5 keV) in unconstrained in the fit, no limits are given in the interval (39,44) keV

And now?

XENON



- Unblinding NR soon, WIMP analysis will follow
- A second science run (SR1) with factor 2 lower radon level is ongoing

Follow us for news on XENON Project!

xenonexperiment.org

xenon_experiment

XENONexperiment

XLZD consortium

Joining effort and expertise between XENON, LZ and DARWIN

xlzd.org

J. Aalbers *et al*, XLZD white paper
arXiv: 2203.02309

Backup

XENON

The tritium hypothesis

Materials would release HTO or HT
We need $^3H:Xe \sim 10^{-24}$ mol/mol

Atmospheric $HTO:H_2O \sim 10^{-17}$ mol/mol

Required $H_2O:Xe \sim 100$ ppb

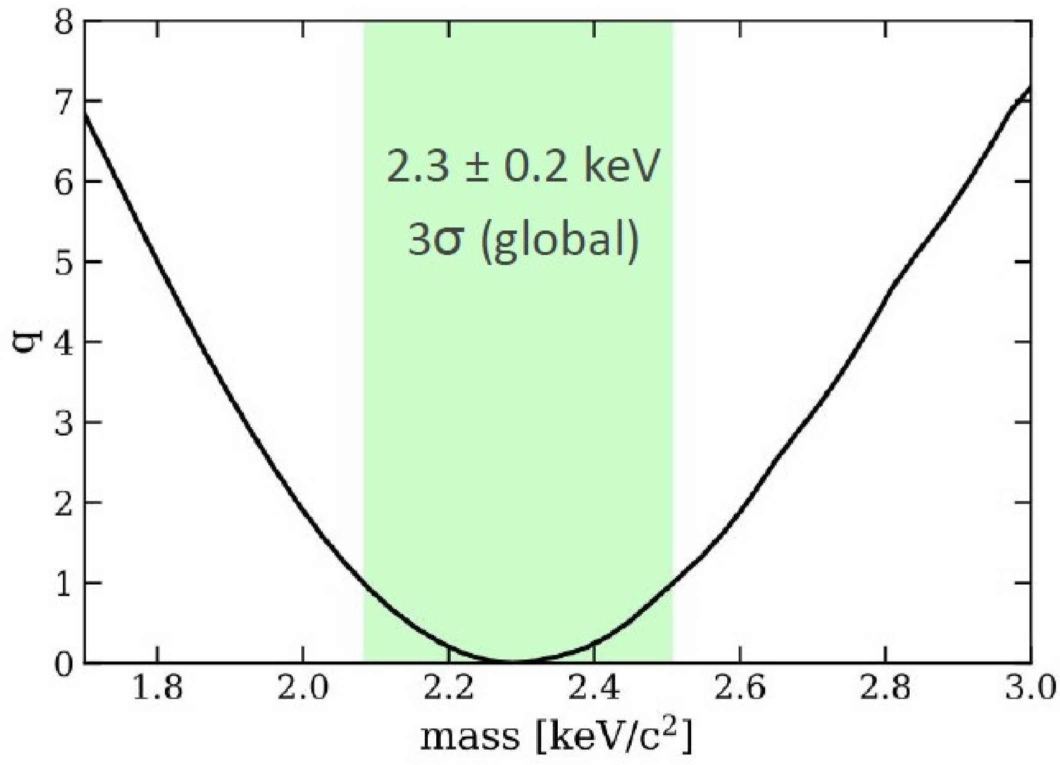
Ruled out by light yield measurement
$H_2O:Xe \sim 1$ ppb

Assuming $HT:H_2 \sim 10^{-17}$ mol/mol

Required $H_2:Xe \sim 100$ ppb

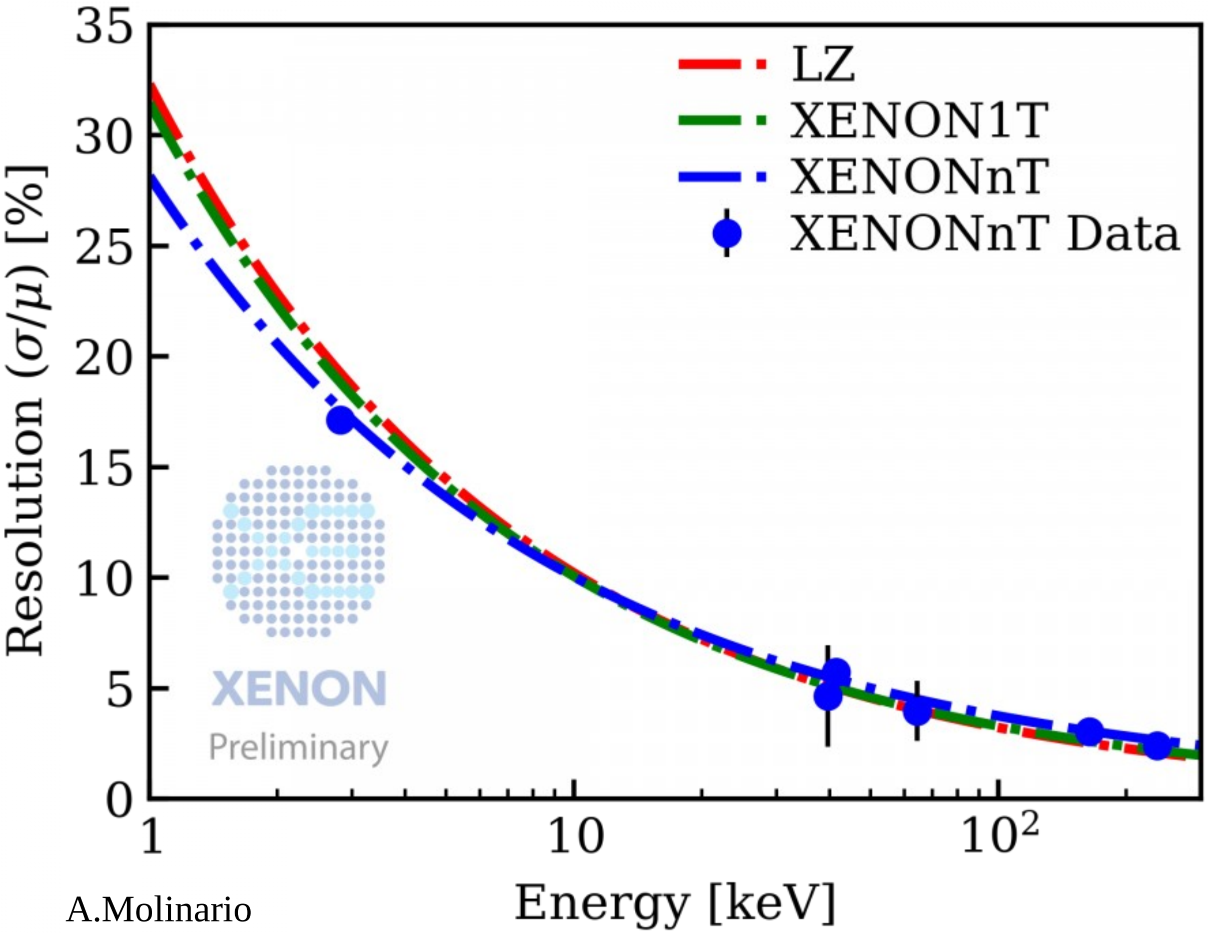
No constraints on $H_2:Xe$

^{37}Ar contamination



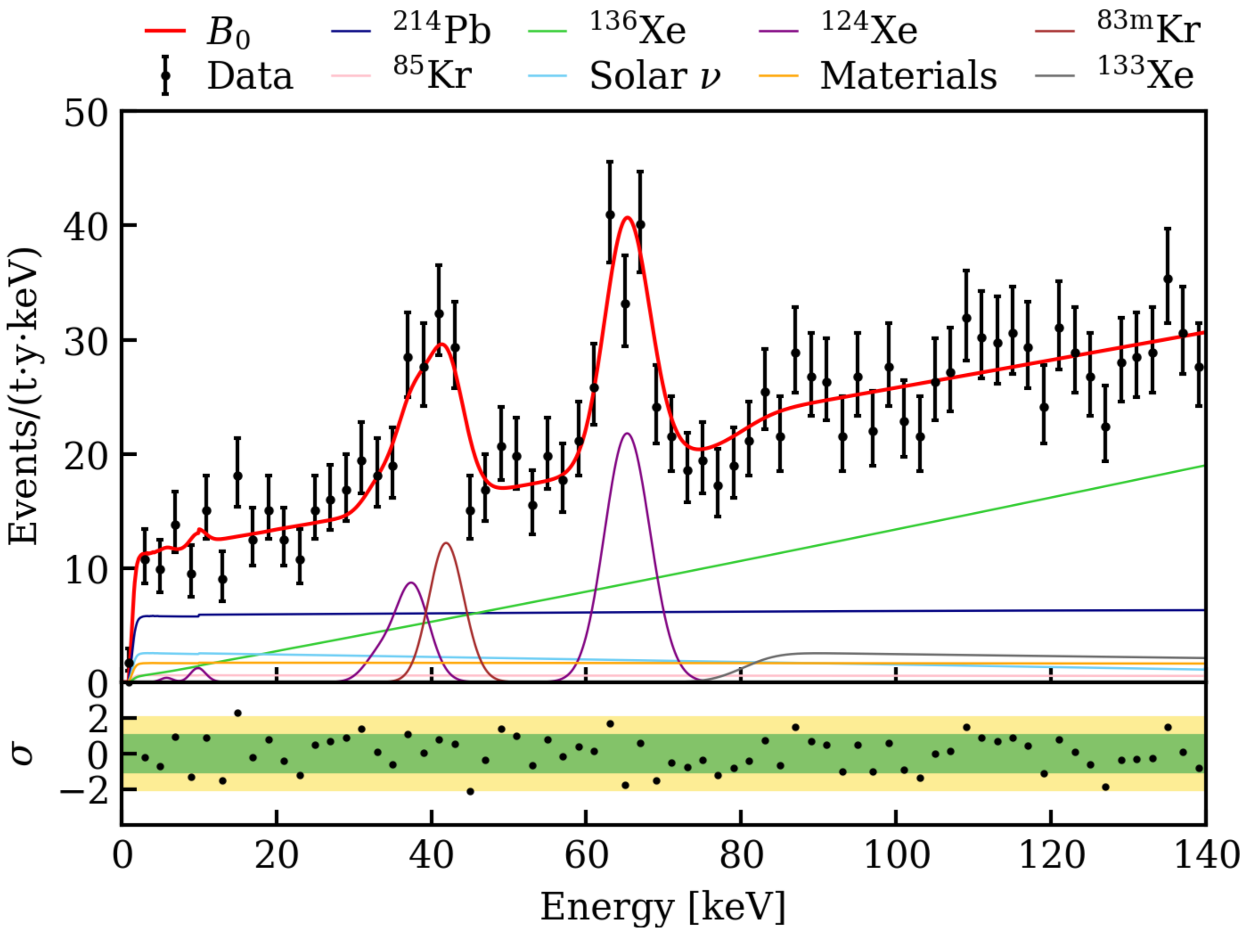
- Air leak in XENON1T < 1 liter/year (rare gas mass spectrometry constraints)
- We need 3 liter/day air leak to account for the excess by ^{37}Ar contamination!
- ^{37}Ar gives monoenergetic line at 2.82 keV_{ee}
- Best mono-energetic line fit at 2.3±0.2 keV_{ee}
- Energy reconstruction in this energy range validated with ^{37}Ar calibration

Energy resolution



- Monoenergetic peaks are fitted with skew gaussian
- Smearing parameters (width, skewness) modeled as function of energy

Background model



Component	Constraint	Fit
^{214}Pb	(584, 1273)	980 ± 120
^{85}Kr	90 ± 59	91 ± 58
Materials	266 ± 51	267 ± 51
^{136}Xe	1537 ± 56	1523 ± 54
Solar neutrino	297 ± 30	298 ± 29
^{124}Xe	-	256 ± 28
AC	0.70 ± 0.04	0.71 ± 0.03
^{133}Xe	-	163 ± 63
^{83m}Kr	-	80 ± 16

arXiv:2207.11330